# Water-filtered infrared-A (wIRA) in acute and chronic wounds

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## Abstract

Water-filtered infrared-A (wIRA), as a special form of heat radiation with a high tissue penetration and a low thermal load to the skin surface, can improve the healing of acute and chronic wounds both by thermal and thermic as well as by non-thermal and non-thermic effects. wIRA increases tissue temperature (+2.7 °C at a tissue depth of 2 cm), tissue oxygen partial pressure (+32% at a tissue depth of 2 cm) and tissue perfusion. These three factors are decisive for a sufficient supply of tissue with energy and oxygen and consequently also for wound healing and infection defense.

wIRA can considerably alleviate pain (without any exception during 230 irradiations) with substantially less need for analgesics (52–69% less in the groups with wIRA compared to the control groups). It also diminishes exudation and inflammation and can show positive immunomodulatory effects. The overall evaluation of the effect of irradiation as well as the wound healing and the cosmetic result (assessed on visual analogue scales) were markedly better in the group with wIRA compared to the control group. wIRA can advance wound healing (median reduction of wound size of 90% in severely burned children already after 9 days in the group with wIRA compared to 13 days in the control group; on average 18 versus 42 days until complete wound closure in chronic venous stasis ulcers) or improve an impaired wound healing (reaching wound closure and normalization of the thermographic image in otherwise recalcitrant chronic venous stasis ulcers) both in acute and in chronic wounds including infected wounds. After major abdominal surgery there was a trend in favor of the wIRA group to a lower rate of total wound infections (7% versus 15%) including late infections following discharge from hospital (0% versus 8%) and a trend towards a shorter postoperative hospital stay (9 versus 11 days).

Even the normal wound healing process can be improved.

The mentioned effects have been proven in six prospective studies, with most of the effects having an evidence level of Ia/Ib.

wIRA represents a valuable therapy option and can generally be recommended for use in the treatment of acute as well as of chronic wounds.

**Keywords:** water-filtered infrared-A (wIRA), infrared-A radiation, wound healing, thermal and non-thermal effects, thermic and non-thermic effects, energy supply, oxygen supply, tissue oxygen partial pressure, tissue temperature, tissue blood flow, reduction of pain, wound exudation, inflammation, immunomodulatory effects, acute wounds, chronic wounds, chronic venous stasis ulcers of the lower legs, problem wounds, wound infections, infection defense, contact-free method, absent expenditure of material, prospective, randomized, controlled, double-blind studies, visual analogue scales (VAS), quality of life, infrared thermography, thermographic image analysis

## Introduction

The application of water-filtered infrared-A (wIRA) for the improvement of healing of acute and chronic wounds and the underlying principles are described more extensively than here in the three reviews [1], [2], [3], which belong together (in total 42 PDF pages). Please refer to these reviews for more details and references. Besides this, two further reviews concerning this subject [4], [5] and one review on a slightly broader subject [6] are available.

## Working mechanisms of wIRA

The experience of the pleasant heat of the sun in moderate climatic zones arises from the filtering of the heat radiation of the sun by water vapor in the Earth's atmosphere [1], [4], [5], [6], [7], [8], see Figure 1. The filter effect of water decreases those parts of infrared radiation (most parts of infrared-B and -C and the absorption bands of water within infrared-A), which would otherwise – by reacting with water molecules in the skin – cause an undesired thermal load to the surface of the skin [1], [4], [5], [6], [7], [8]. Technically, water-filtered infrared-A (wIRA) is produced by special radiators, whose full spectrum of radiation of a halogen bulb is passed through a cuvette containing water, which absorbs or decreases the described undesired wavelengths of the infrared radiation [1], [9], see Figure 2. Within the infrared range, the remaining wIRA (within 780–1400 nm) mainly consists of radiation with good tissue penetration properties and therefore allows – compared to unfiltered heat radiation – a multiplication of the energy transfer into tissue without irritating the skin, similar to the sun's heat radiation in moderate climatic zones. Typical wIRA radiators emit no ultraviolet (UV) radiation and almost no infrared-B and -C radiation and the amount of infrared-A radiation in relation to the amount of visible light (380–780 nm) is accentuated [1], [9], see Figure 3.
Within the spectra of infrared-A and water-filtered infrared-A, radiation effects in particular of the energy-rich wavelengths near to visible light – approximately 780–1000 nm (800–900 nm [10], [11], [12], 800 nm [13], 820 nm [14], [15], [16], 830 nm [17]) – have been described both in vitro and in vivo. These wavelengths seem to represent the clinically most important part of the infrared-A and wIRA range [1], [18].
Water-filtered infrared-A as a special form of heat radiation with a high tissue penetration and with a low thermal load to the skin surface (see Figure 4), acts both by thermal (related to heat energy transfer) and thermic (temperature dependent, with a relevant change of temperature) as well as by non-thermal (without a relevant transfer of heat energy) and non-thermic (not depending on temperature, without a relevant change of temperature) effects [1]. wIRA produces a therapeutically usable field of heat in the tissue and increases tissue temperature [19], [20], [21], [22], [23], [24], [25], [26], tissue oxygen partial pressure [19], and tissue perfusion [1], [24], [25], [26]. These three factors are vital for a sufficient supply of tissue with energy and oxygen.
As wound healing and infection defense (e.g. granulocyte function including its antibacterial oxygen radical formation) depend decisively on a sufficient supply of tissue with energy and oxygen and since the centers of chronic wounds are often relatively hypothermic [1], [19], [23] (while e.g. both preoperative [27] and postoperative [19], [28] heat supply to the operation field can improve healing of acute wounds) and frequently have an oxygen partial pressure close to zero [1], [19], [23], [29], [30], [31], [32], [33], [34], [35], [36], [37], [38], one explanation for the good clinical effect of wIRA on wounds and wound infections could be the improvement of both the energy supply per time (increase of metabolic rate) and the oxygen supply [1]. In addition, wIRA has non-thermal and non-thermic effects, which are based on a direct stimulation of cells and cellular structures: Reactions of cells to infrared radiation – partly found even at very small irradiances – are e.g. target-oriented growth of surface extensions (plasmodia) [10], influence on cytochrome c oxidase [14], [39], [40], target-oriented growth of neurons [13], stimulation of wound repair [41], [42] as well as cell protective effects of infrared-A [43], [44], [45], [46] and water-filtered infrared-A (wIRA) [47], [48], [49].
wIRA can considerably alleviate pain (with remarkably less need for analgesics) and diminish an elevated wound exudation and inflammation and can show positive immunomodulatory effects. wIRA can advance wound healing or improve an impaired wound healing both in acute and in chronic wounds, including infected wounds. Even the normal wound healing process can be improved [1], [19].
wIRA is contact-free, easily applied, involves no discomfort to the patient or the use of expendable materials and is effective even in deeper-lying tissue regions. wIRA application, with appropriate therapeutic irradiances and doses, could be shown not only to be harmless for human skin [1], [4], [18], [47], [48], [50], but even to have protective effects in cells against damage caused by UV radiation [1], [4], [43], [44], [45], [46], [47], [48], [49]. Safety aspects of the clinical use of wIRA have been described extensively, especially in [1] and [18]. Particularly when [50] and the current review [51] are taken into consideration, the application of wIRA with adequate irradiances can be considered as being safe. The irradiation of the typically uncovered wound is carried out using a wIRA radiator, see Figure 5.

## Clinical effects of wIRA on wounds

Based on 6 clinical studies, the following has been proven with a level of evidence of Ia/Ib [1], [52]:

- acute pain reduction during wIRA irradiation
- reduction of the required dose of analgesics
- faster reduction of wound area
- better assessment of wound healing
- better overall evaluation of the effects of irradiation (including pain, wound healing, cosmesis)
- higher tissue oxygen partial pressure during wIRA
- higher subcutaneous temperature during wIRA
- better cosmesis

In addition, the following trends have been found:

- lower rate of wound infections
- shorter postoperative hospital stay

Additional clinical observations are:

- reduction of inflammation
- reduction of hypersecretion

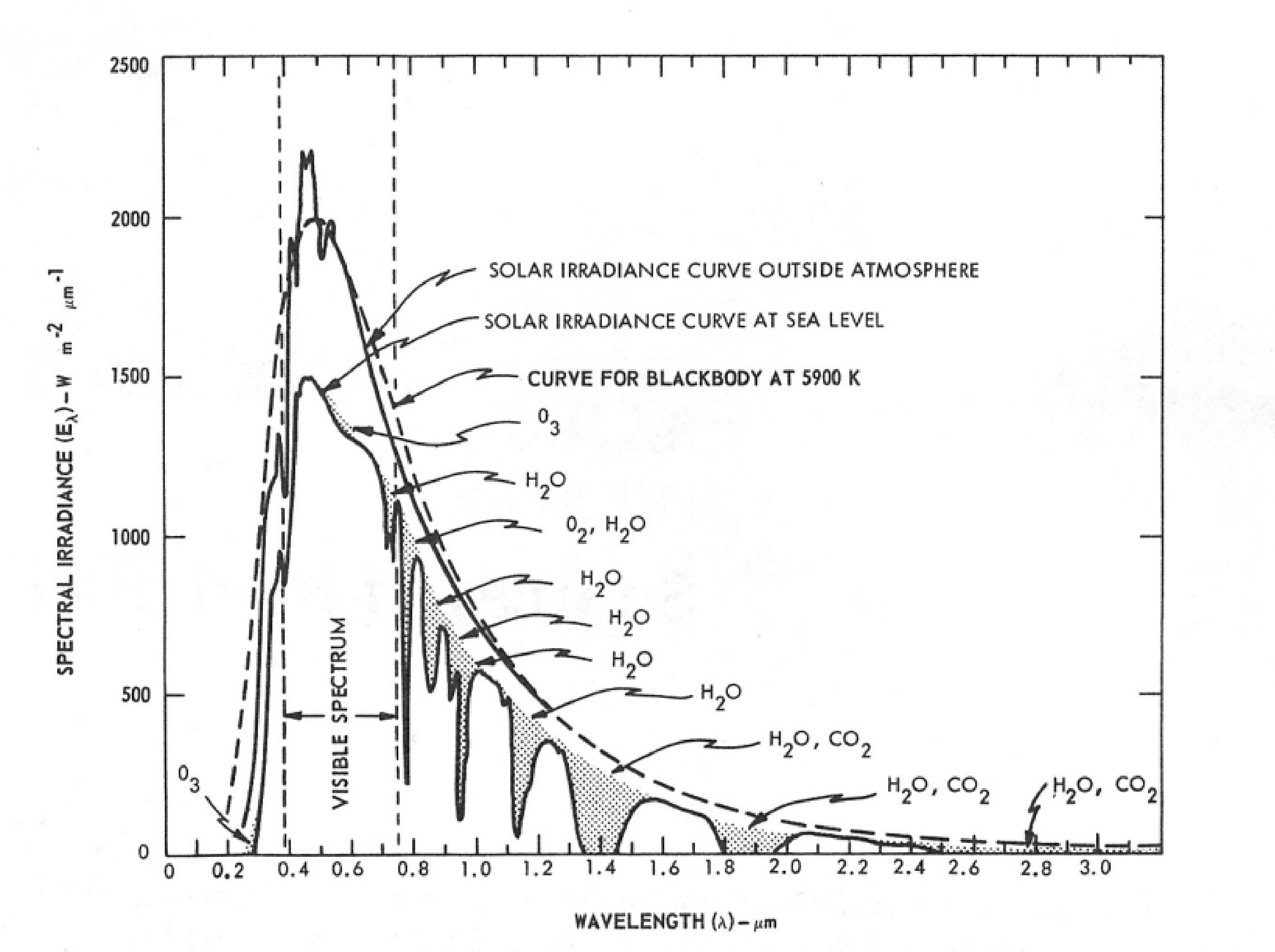


**Figure 1: Spectral solar irradiance outside the atmosphere and on the surface of the Earth at sea level,**
in both cases with the sun at the zenith and for a mean Earth-sun distance. Shaded areas indicate absorption before reaching the surface of the Earth at sea level due to the atmospheric constituents shown (from [1], [58], adapted from [59]).
For comparison of Figures 1 and 3: $1000\ W \cdot m^{-2} \cdot µm^{-1} = 100\ mW \cdot cm^{-2} \cdot µm^{-1} = 1\ mW \cdot cm^{-2} \cdot (10\ nm)^{-1}$

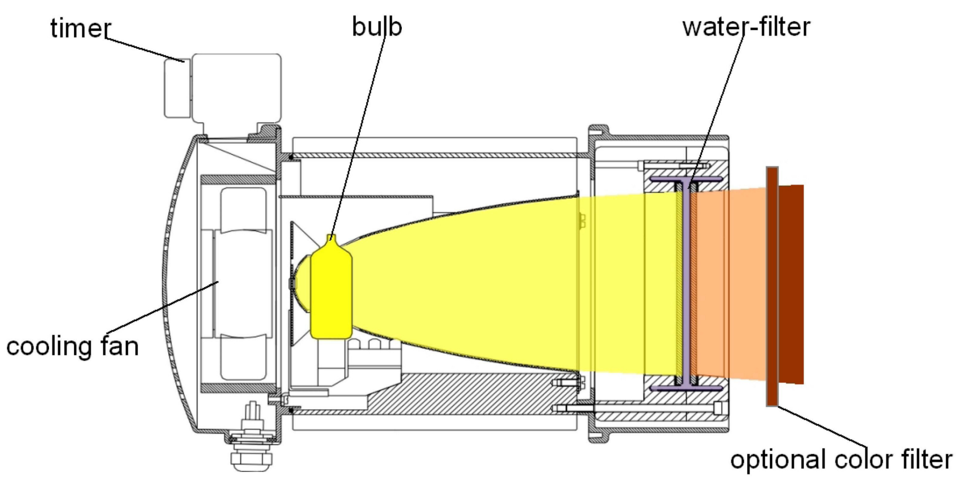


**Figure 2: Cross-section of a water-filtered infrared-A radiator (Hydrosun, Müllheim, Germany)**
The whole incoherent non-polarized broadband radiation of a 3000 Kelvin halogen bulb is passed through a cuvette containing water, which absorbs or decreases the undesired wavelengths within the infrared region (most parts of infrared-B and -C and the absorption bands of water within infrared-A). The water is hermetically sealed within the cuvette. A fan provides air cooling of the cuvette to prevent the water from boiling. (from [1])

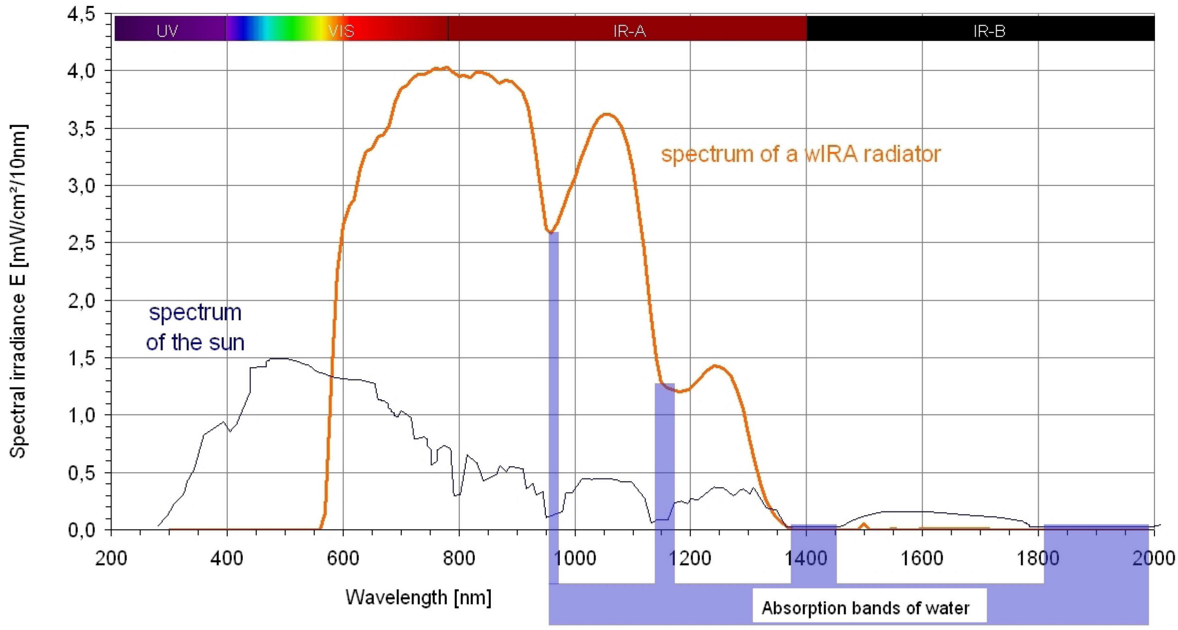


**Figure 3: Comparison of the spectra of the sun on the surface of the Earth at sea level and of a water-filtered infrared-A radiator**
Spectral solar irradiance on the surface of the Earth at sea level (with the sun at the zenith and for a mean Earth-sun distance) as in Fig. 1 (from [1], adapted from [58]) and spectral irradiance of a water-filtered infrared-A radiator (Hydrosun® radiator 501 with 10 mm water cuvette and orange filter OG590) at approximately 210 mW/cm² (= $2.1 \cdot 10^3$ W/m²) total irradiance (from [1], [4]).
The spectrum of the sun at sea level includes ultraviolet radiation (UV, <400 nm), visible light (VIS, 380–780 nm), and infrared radiation (IR, >780 nm). The spectrum of the water-filtered infrared-A radiator includes only visible light (VIS) and infrared radiation (IR); the visible part depends on the color filter used; the wIRA radiator does not emit ultraviolet radiation (UV).
Both spectra show the decreased irradiances of the absorption bands of water.

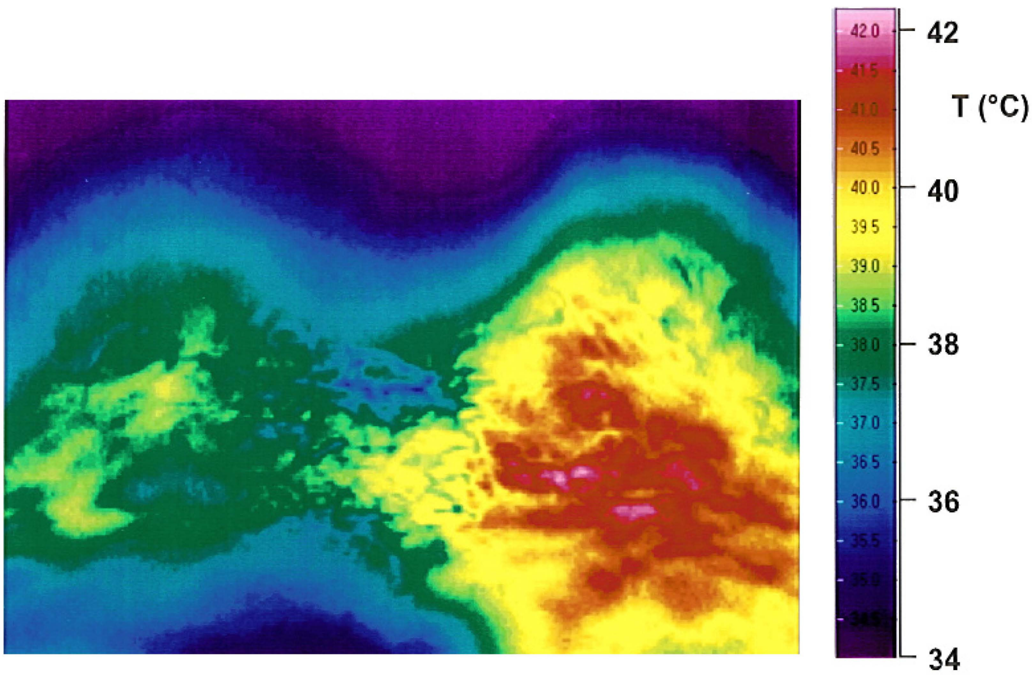


**Figure 4: Comparison of irradiation with water-filtered infrared-A and with conventional infrared**
Thermographical comparison of skin surface temperatures in the lumbar region 12 minutes after commencement of irradiation with water-filtered infrared-A (left) and conventional infrared (right) with the same irradiance: the skin surface temperature is higher in the case of irradiation with conventional infrared (presented in the thermography), while the temperature at 1 cm tissue depth is higher when irradiating with water-filtered infrared-A (from [1], [20]). Water-filtered infrared-A thus leads to a high tissue penetration combined with a low thermal load to the skin surface.

**Figure 5: Example of an irradiation of a wound with a water-filtered infrared-A radiator**
(published with kind approval of Prof. James Mercer, Tromsø/Norway) (from [1], [23])

# Therapy of acute wounds with wIRA

## wIRA for acute operation wounds (Study of the University Hospital Heidelberg, Department of Surgery)

A prospective, randomized, controlled, double-blind study with 111 patients who had undergone major abdominal surgery at the University Hospital Heidelberg, Germany, and thereafter underwent 20 minutes irradiation 2 times per day (starting on the second postoperative day) showed a significant and relevant pain reduction combined with a markedly decreased dose of required analgesics in the group with wIRA and visible light VIS (wIRA(+VIS), approximately 75% wIRA, 25% VIS) compared to a control group with only VIS: during 230 single irradiations with wIRA(+VIS) pain decreased without any exception (median of decrease of pain on postoperative days 2–6 was 13.4 on a 100 mm visual analogue scale VAS 0–100), while pain remained unchanged in the control group (p<0.000001, see Figure 6). The median of decrease of pain on the third postoperative day was 18.5 versus 0.0, the median difference between the groups was 18.4 (99% confidence interval 12.3/21.0), p<0.000001. (Semantic statistical remark in [2], [5].)

The required dose of analgesics was 52–69% lower (median differences) in the subgroups with wIRA(+VIS) compared to the control subgroups with only VIS (median 598 versus 1398 mL ropivacaine, p=0.000020, for peridural catheter analgesia; 31 versus 102 mg piritramide, p=0.00037, for patient-controlled analgesia; 3.4 versus 10.2 g metamizole, p=0.0045, for intravenous and oral analgesia, see Figure 7).

During irradiation with wIRA(+VIS) the subcutaneous oxygen partial pressure rose markedly by 32% and the subcutaneous temperature by 2.7 °C (both measured at a tissue depth of 2 cm), whereas both remained unchanged in the control group. After irradiation, the median of the subcutaneous oxygen partial pressure was 41.6 (with wIRA) versus 30.2 mm Hg in the control group (median difference between the groups 11.9 mm Hg (+39%), 99% confidence interval 8.4/15.4 mm Hg (+28%/+51%), p<0.000001, see Figure 8) and the median of the subcutaneous temperature was 38.9 versus 36.4 °C (median difference between the groups 2.6 °C, 99% confidence interval 2.1/2.9 °C, p<0.000001, see Figure 9). The baseline values (before irradiation) of the subcutaneous oxygen partial pressure rose from the second to the tenth postoperative day by 3.4 versus 0.3 mm Hg (median difference between the groups 3.1 mm Hg (+10%), 99% confidence interval 1.9/3.7 mm Hg, p=0.00051). The baseline values for the subcutaneous temperature rose by 0.4 versus –0.3 °C (median difference 0.6 °C, 95% confidence interval 0.2/0.8 °C, p=0.0074) (effects which endured beyond the time period of the single irradiation).

The overall evaluation of the effect of irradiation, including wound healing, pain and cosmesis, assessed on a VAS (0-100 with 50 as the indifferent point of no effect) by the surgeon (median 79.0 versus 46.8, median difference 27.9, 99% confidence interval 17.2/37.3, p<0.000001) or the patient (79.0 versus 50.2, median difference 23.8, 99% confidence interval 9.5/34.1, p=0.000007) was considerably better in the group with wIRA compared to the control group. This was also true for single aspects: Wound healing assessed on a VAS by the surgeon (median 88.6 versus 78.5, p<0.000001) or the patient (median 85.8 versus 81.0, p=0.040, trend) and cosmetic result assessed on a VAS by the surgeon (median 84.5 versus 76.5, p=0.00027) or the patient (median 86.7 versus 73.6, p=0.00077).

In addition there was a trend towards a lower rate of total wound infections in favor of the wIRA group (3 of 46, 7%, versus 7 of 48, 15%, difference –8%, 95% confidence interval –20%/4%, p=0.21) including late infections following discharge. This was due to the different rate of late infections following discharge: 0 of 46 (0%) in the wIRA group and 4 of 48 (8%) in the control group (difference –8%, 95% confidence interval –18%/2%, p=0,12).

There was also a trend towards a shorter postoperative hospital stay: 9 days in the wIRA group versus 11 days in the control group (median difference –2 days (–18%), 95% confidence interval –3/0 days, p=0.022).

The principal finding of this study was that postoperative irradiation with wIRA can improve even the normal wound healing process [2], [19].

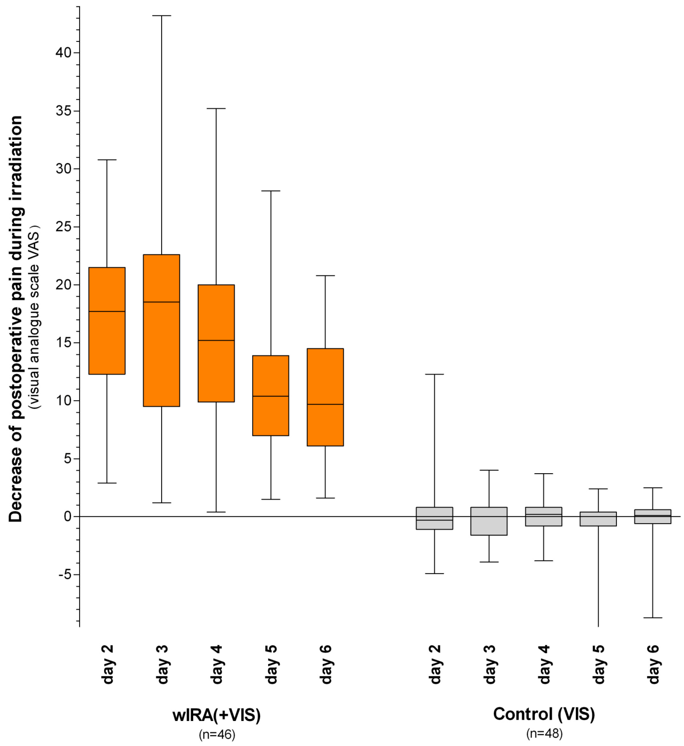


**Figure 6: Decrease of postoperative pain during irradiation in the group with water-filtered infrared-A (wIRA) and visible light (VIS) and in the control group with only visible light (VIS) (Study Heidelberg)**
(assessed with a visual analogue scale; given as minimum, percentiles of 25, median, percentiles of 75, and maximum (box and whiskers graph with the box representing the interquartile range), from [2], adapted from [19]).
During 230 single irradiations with wIRA(+VIS) the pain decreased without any exceptions, while pain remained unchanged in the control group (p<0.000001 for any single documented day as well as for all the days).

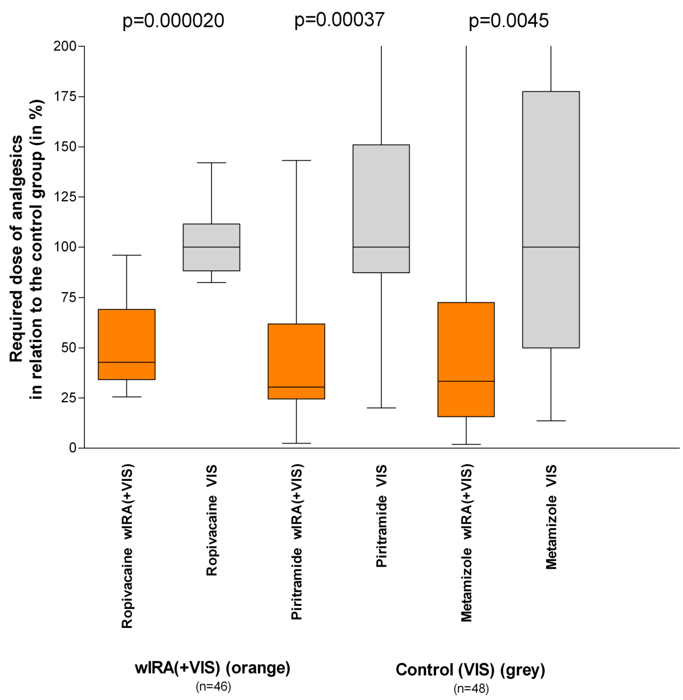


**Figure 7: Required dose of analgesics of the subgroups with water-filtered infrared-A (wIRA) and visible light (VIS) in relation to the control subgroups with only visible light (VIS) (medians of the control subgroups = 100) (Study Heidelberg)**
(given as minimum, percentiles of 25, median, percentiles of 75, and maximum (box and whiskers graph with the box representing the interquartile range), adapted from [2], data taken from [19]).
The required dose of analgesics was 52–69% lower (median differences) in the subgroups with wIRA(+VIS) compared to the control subgroups with only VIS.

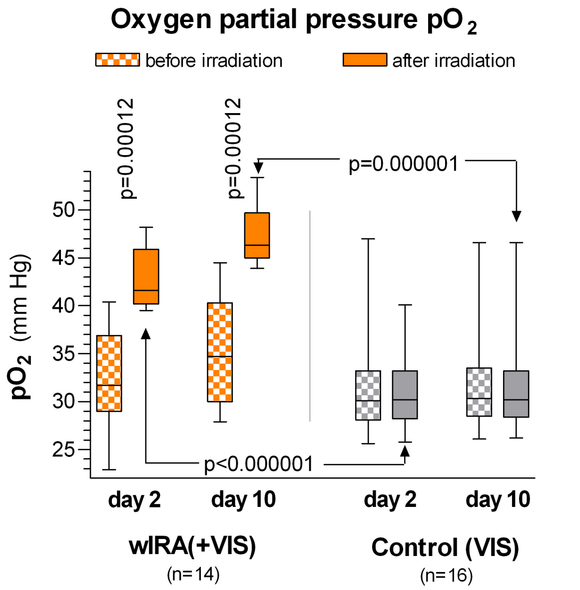


**Figure 8: Subcutaneous oxygen partial pressure at a tissue depth of 2 cm on the postoperative days 2 and 10 in the group with water-filtered infrared-A (wIRA) and visible light (VIS) and in the control group with only visible light (VIS) (Study Heidelberg)**

(given as minimum, percentiles of 25, median, percentiles of 75, and maximum (box and whiskers graph with the box representing the interquartile range); adapted from [2], [19]). During irradiation with wIRA(+VIS), the subcutaneous oxygen partial pressure rose markedly by more than 30%, whereas it remained unchanged in the control group.

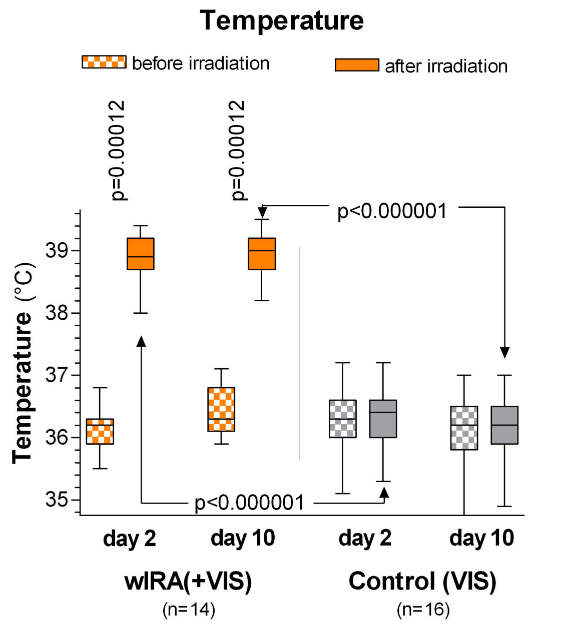


**Figure 9: Subcutaneous temperature at a tissue depth of 2 cm on the postoperative days 2 and 10 in the group with water-filtered infrared-A (wIRA) and visible light (VIS) and in the control group with only visible light (VIS) (Study Heidelberg)**

(given as minimum, percentiles of 25, median, percentiles of 75, and maximum (box and whiskers graph with the box representing the interquartile range); adapted from [2], [19]). During irradiation with wIRA(+VIS) the subcutaneous temperature rose markedly by approximately 2.7 °C, whereas it remained unchanged in the control group.

## wIRA for severely burned children (Study of the Children's Hospital Park Schönfeld, Kassel, Department of Pediatric Surgery)

A prospective, randomized, controlled, double-blind study with 45 severely burned children was carried out at the Children's Hospital Park Schönfeld, Kassel, Germany. 30 minutes irradiation was applied once a day (starting on the first day, with the day of burn being day 1). In the group with wIRA and visible light VIS (wIRA(+VIS), approximately 75% wIRA, 25% VIS) a markedly faster reduction of wound size was seen in comparison to a control group with only VIS. On the fifth day (after 4 days with irradiation), the decision was taken as to whether surgical debridement of necrotic tissue was necessary because of deeper (second degree, type b) burns (11 of 21 in the group with wIRA, 14 of 24 in the control group) or whether non-surgical treatment was possible (second degree, type a burns). The patients treated conservatively were kept within the study and irradiated until reepithelialisation was complete.

The patients in the group with wIRA showed a markedly faster reduction of wound area: a median reduction of wound size of 50% was reached already after 7 days compared to 9 days in the control group, a median reduction of wound size of 90% was already achieved after 9 days compared to 13 days in the control group, see Figure 10 and Figure 11. After 9 days, the median reduction in wound area was 89.2% versus 49.5%, the median difference between the groups was a 39.5% reduction of the wound area (99% confidence interval 34.4%/43.0%), p=0.000011. The median difference between the groups existed already after one day with p=0.00013 and after 2, 5, 6, 7, 8, 9, 10 and 11 days with p<0.0001. In addition, the group with wIRA showed superior results in terms of the overall surgical assessment of the wound and the assessment of effects of irradiation (the latter as a trend up to 3 months after the burn) compared to the control group [2].

## wIRA for experimental wounds (Study of the University Medical Center Charité Berlin, Department of Dermatology)

In a prospective, randomized, controlled study with 12 volunteers at the University Medical Center Charité, Berlin, Germany, volunteers were inflicted with 4 experimental superficial wounds (5 mm diameter). In this acute wound model, wounds were generated by a suction cup technique, with the roof of the blister being removed with a scalpel and sterile forceps (day 1). 4 different treatments were used and investigated over 10 days: no therapy, wIRA(+VIS) only (approximately 75% wIRA, 25% VIS; 30 minutes irradiation once a day), only dexpanthenol (= D-panthenol) cream once a day, wIRA(+VIS) and dexpanthenol cream once a day. Healing of the small experi-

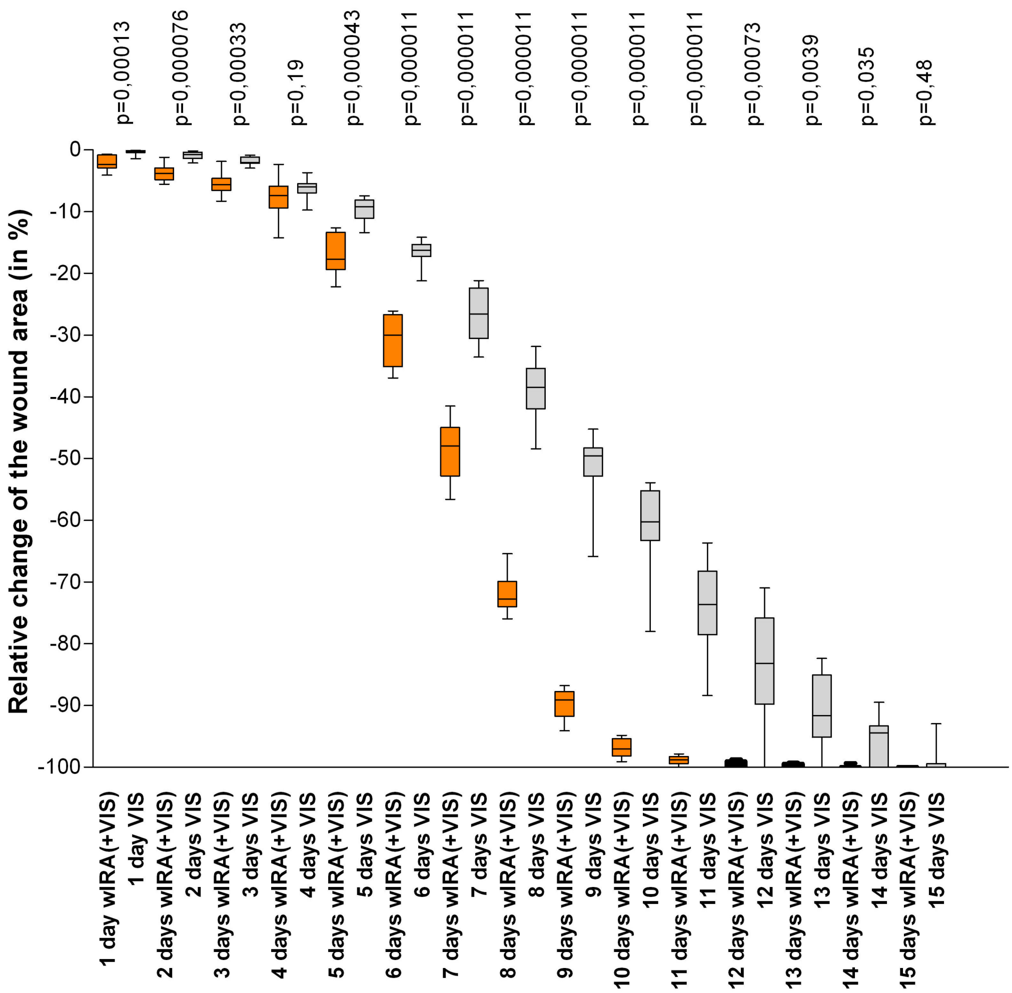


**Figure 10: Relative change of wound area in severely burned children as a function of duration of treatment (in days) in the group with water-filtered infrared-A (wIRA) and visible light (VIS) and in the control group with only visible light (VIS) (Study Kassel)**

(given as minimum, percentiles of 25, median, percentiles of 75, and maximum (box and whiskers graph with the box representing the interquartile range), adapted from [2]). The figure presents the data from those 10+10 = 20 children (out of 21+24 = 45 children), who had second degree, type a burns (not second degree, type b burns) and were consequently treated non-surgically until complete cutaneous regeneration occurred including irradiation (starting on the day of the burn, until complete reepithelialization) with wIRA(+VIS) or with only VIS (control group). Patients in the group with wIRA showed a markedly faster reduction of wound area compared to the control group: a median reduction of wound size of 50% was reached in the group with wIRA already after 7 days compared to 9 days in the control group, a median reduction of wound size of 90% was achieved in the group with wIRA already after 9 days compared to 13 days in the control group.

**Figure 11: Example of a rapid improvement with wIRA in a severely burned child (Study Kassel)**

Left: 1 day after the burn, right: only 30 hours later than shown on the left side (from [2]).

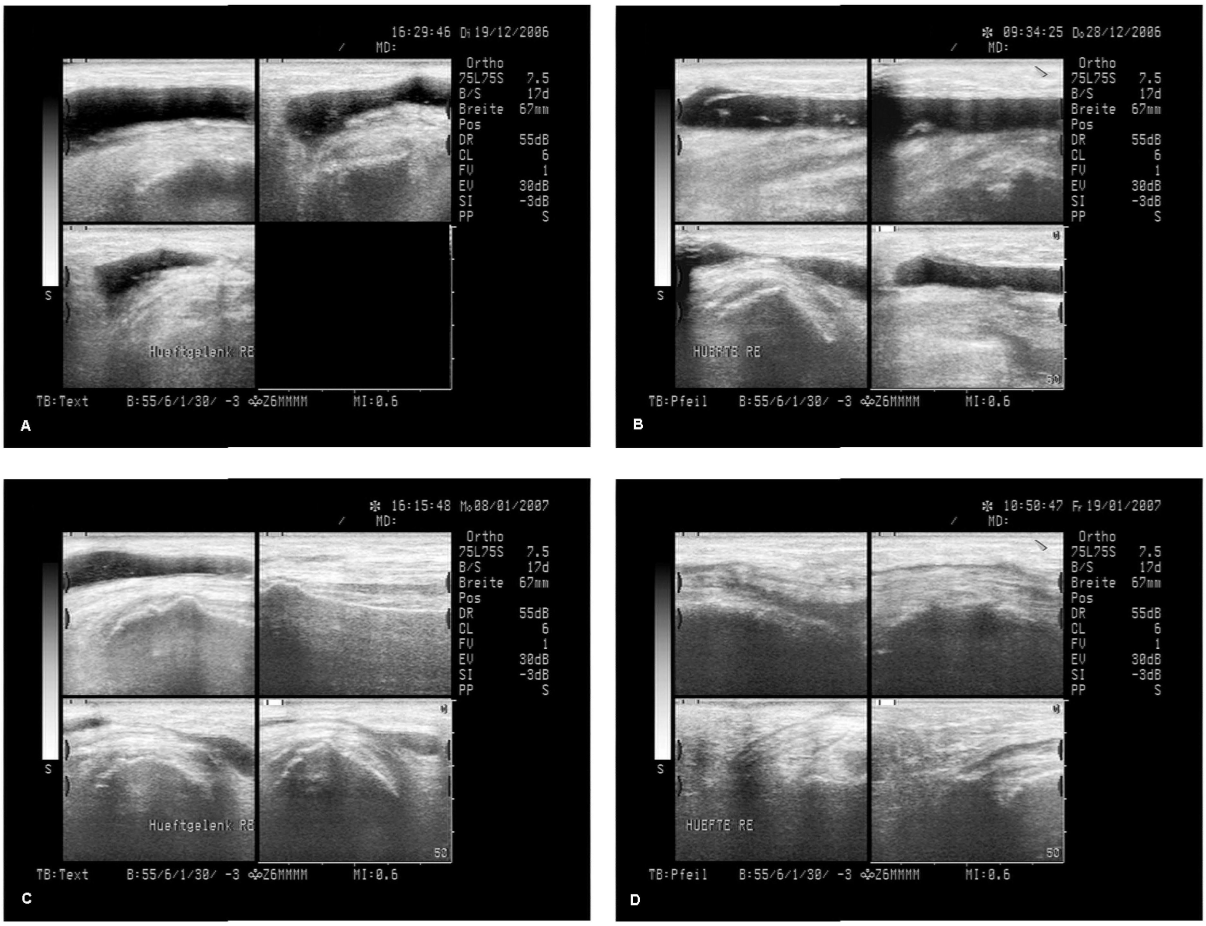


**Figure 12: Example of a successful treatment of recurrent wound seromas with wIRA**

A 64 year-old female patient had relapsing wound seromas and wound hematomas (without infection) after a hip operation (replacement of the acetabulum part of a 15 year-old endoprosthesis) even after an additional operation with the sole intention of stopping the wound seromas and after approximately 8 aspirations of seroma fluid (up to approximately 90 mL within one aspiration) within 2 months, and a third operation was seriously considered: Figure A shows the sonographic state. At that time, wIRA(+VIS) irradiation was commenced, beginning with 30 minutes twice per day and increasing up to 3 times one hour per day. Within a few days the seroma no longer increased as usual; after approximately one week a slight decrease of seroma size was noticed clinically (Figure B). Figure C shows reduced seroma size after 18 days and Figure D after 29 days. After approximately 2 months the seroma had resolved completely (both clinically and sonographically) without any aspiration of seroma fluid or operation since commencement of wIRA(+VIS) irradiation (sonographic pictures published with kind approval of Dr. Michael Paulus, Herzogenaurach, Germany) (from [2]).

mental wounds was, from a clinical point of view, excellent with all 4 treatments. Therefore there were only small differences between the treatments with slight advantages seen with the combination wIRA(+VIS) and dexpanthenol cream and with dexpanthenol cream alone as far as relative change of wound size and assessment of feeling of the wound area were concerned.

Laser scanning microscopy, however, together with a scoring system revealed differences between the 4 treatments concerning the formation of the stratum corneum (from first layer of corneocytes to full formation) especially on days 5–7: the fastest formation of the stratum corneum was seen in wounds treated with wIRA(+VIS) and dexpanthenol cream, second was wIRA(+VIS) alone, third dexpanthenol cream alone and lastly, untreated wounds. Bacterial counts of the wounds (taken every 2 days) showed that wIRA(+VIS) and the combination of wIRA(+VIS) with dexpanthenol cream were able to inhibit the colonisation with physiological skin flora up to day 5 when compared with the two other groups (untreated group and group with dexpanthenol cream alone). At any investigated time, the amount of colonisation under therapy with wIRA(+VIS) alone was lower (interpreted as being more suppressed) compared with the group with wIRA(+VIS) and dexpanthenol cream [2].

## wIRA for wound seromas

During rehabilitation after hip and knee endoprosthetic operations the resorption of wound seromas and wound hematomas was both clinically and sonographically faster and pain was reduced by irradiation with wIRA(+VIS) [2]. An additional example is presented in Figure 12.

### wIRA for persistent postoperative pain

wIRA can be used successfully for persistent postoperative pain e.g. after thoracotomy [2].

### Perspectives for wIRA for the improvement of healing of acute wounds

As far as perspectives for the use of wIRA are concerned, it seems clinically prudent to use wIRA both pre- and postoperatively, e.g. in abdominal and thoracic operations. wIRA can be used preoperatively (e.g. over 1–2 weeks) to precondition donor and recipient sites of skin flaps, transplants or partial-thickness skin grafts, and postoperatively to improve wound healing and to decrease pain, inflammation and infections at all mentioned sites. wIRA can be used to support routine pre- or intraoperative antibiotic administration or even a replacement of the latter with wIRA can be discussed under certain conditions [2].

## Therapy of chronic wounds with wIRA

The central portion of chronic wounds is often hypoxic and relatively hypothermic, representing a deficient energy supply of the tissue, which impedes wound healing or even makes it impossible. wIRA increases temperature, oxygen partial pressure and perfusion of the tissue. These three factors are decisive for a sufficient supply of tissue with energy and oxygen and consequently for wound healing, especially in chronic wounds, and infection defense. wIRA can enable wound healing in non-healing chronic wounds [3].

### wIRA for chronic venous stasis ulcers of the lower legs (Study in Basel)

In a prospective, randomized, controlled study of 40 patients with chronic venous stasis ulcers of the lower legs, irradiation with wIRA and visible light VIS 30 minutes three times per week over 6 weeks accelerated the wound healing process (on average 18 versus 42 days until complete wound closure, residual ulcer area after 42 days 0.4 cm² versus 2.8 cm²) and led to a reduction of the required dose of pain medication in comparison to the control group of patients treated with the same standard care (wound cleansing, wound dressing with antibacterial gauze, and compression therapy) without concomitant irradiation [3], [53].

### wIRA for chronic venous stasis ulcers of the lower legs (Study of the University of Tromsø/Norway and the Hospital in Hillerød/Denmark)

Another prospective study of 10 patients with non-healing chronic venous stasis ulcers of the lower legs included extensive thermographic investigation. Therapy with wIRA(+VIS) resulted in a complete or almost complete wound healing in 7 patients and a marked reduction of the ulcer size in a further 2 of the 10 patients, a clear reduction of pain and required dose of pain medication (e.g. from 15 to 0 pain tablets per day), and a normalization of the thermographic image (before the beginning of the therapy, a hyperthermic rim of the ulcer together with a relative hypothermic ulcer base and a temperature difference of up to 4.5 °C was typically seen).

In one patient the therapy of an ulcer of one leg was performed with the fully active radiator (wIRA(+VIS)), while the therapy of an ulcer of the other leg was carried out with a control group radiator (only VIS without wIRA), showing a clear difference in favor of the wIRA treatment.

All variables assessed with visual analogue scales – effect of the irradiation (assessed by patient and by clinical investigator), feeling of the wound area (assessed by patient), wound healing (assessed by clinical investigator), and cosmetic state (assessed by patient and by clinical investigator) – improved remarkably during the period of irradiation treatment, representing an increased quality of life.

Within the group of 6 patients with chronic venous stasis ulcers of the lower legs without any concomitant problems (i.e. without arterial insufficiency, without being a smoker and without lacking compression therapy) all 6 ulcers healed completely or almost completely (96–100% reduction of ulcer size) [3], [23].

The original publication [23] provides 10 appendices with detailed information about each patient und in addition two thermographic video sequences.

An example of the healing process in a chronic venous stasis ulcer of the lower leg under therapy with wIRA is presented in Figure 13.

### wIRA for chronic venous stasis ulcers of the lower legs (Study of the University of Freiburg, Department of Dermatology)

In a prospective, randomized, controlled, blinded study, 51 patients with non-healing chronic venous stasis ulcers of the lower legs were treated with compression therapy, wound cleansing, non-adhesive wound dressings and 30 minutes irradiation five times per week over 9 weeks. A preliminary analysis of this study has shown advanced wound healing, improved granulation and in the later phase of treatment a decrease of the bacterial burden in the group with wIRA(+VIS) compared to a control group with VIS only [3].

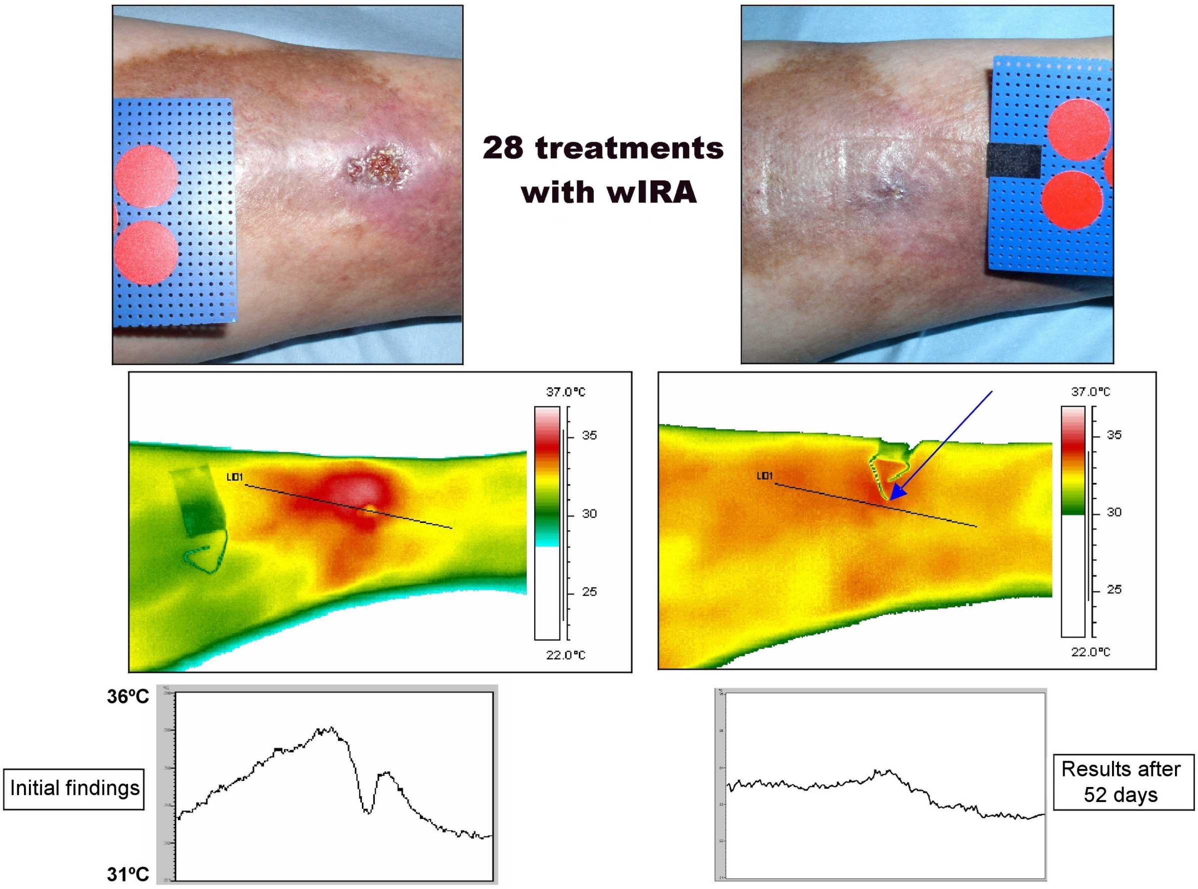


**Figure 13: Example of the healing process of a chronic venous stasis ulcer of the lower leg under therapy with wIRA (Study Tromsø/Hillerød)**
(28 times 30 minutes irradiation with water-filtered infrared-A (wIRA) and visible light (VIS) within 52 days = approximately 7 weeks) with normal view, thermographic image, and temperature profile across the ulcer, in each case to the left before therapy and to the right after completion of the course of therapy. The arrow in the thermographic image - taken after completion of the course of therapy - points to the place where the wound has been. Diameter of the red circles: 16 mm. (Study of the University of Tromsø/Norway and the Hospital in Hillerød/Denmark) (adapted from [3], [4], [23])

## wIRA for chronic venous stasis ulcers of the lower legs (Example)

An additional example is presented in Figure 14.

## Other wound-related indications of wIRA

Some case reports have demonstrated that wIRA can even be used for mixed arterial-venous ulcers or arterial ulcers, if an appropriately low irradiation intensity is chosen and if irradiation is monitored carefully [3].
wIRA can be used for decubital ulcers both as a preventive and as a therapeutic measure [3].
wIRA can also improve the resorption of topically applied substances [54], [55], [56] in wounds [3].

## Endogenous PDT-like effect of wIRA

An irradiation with VIS and wIRA presumably acts with endogenous protoporphyrin IX (or protoporphyrin IX of bacteria) in a manner similar to a mild photodynamic therapy (endogenous PDT-like effect). This could lead to improved cell regeneration and wound healing and to antibacterial effects [3], [57].

## Perspectives for wIRA for the improvement of healing of chronic wounds

In conclusion, these results indicate that wIRA can generally be recommended for use in the treatment of chronic wounds [3].

# Résumé

wIRA can considerably alleviate pain, is capable of diminishing exudation and inflammation and can reduce infections. wIRA can advance wound healing or improve an impaired wound healing both in acute and in chronic wounds. Even the normal wound healing process can be improved.
wIRA can generally be recommended for use in the treatment of acute as well as of chronic wounds.


**Figure 14: Example of the healing process of a chronic venous stasis ulcer of the lower leg under therapy with wIRA**
88 year-old woman with an infected (lightly malodorous) crustaceous ulcer (of the right distal medial lower leg), which had persisted for 13 months and had increased despite conservative dermatological therapy including local antisepsis, systemic antibiotic, and non-adhesive wound dressing up to 10 cm in diameter. Chronic venous insufficiency with marked stasis-related edemas of the lower legs and extensive stasis dermatitis, diabetes mellitus type II (orally treated), slightly overweight, and decreased amount of daily motion. Under irradiation with wIRA(+VIS) 30 minutes once daily, compression therapy, local antisepsis, non-adhesive wound dressing and the possibility of ending the systemic antibiotic therapy, a complete wound closure was achieved within 4½ months: initial findings, result after 3½ months, result after 4½ months (healed) (adapted from [3], [4])

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